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A PARACHUTE RECOVERY TEST OF A FULL-SCALE FREE-FLIGHT MODEL OF AN AIR-TO-SURFACE MISSILE WITH RECOVERY INITIATED AT A MACH NUMBER OF 1.43

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-451

A PARACHUTE RECOVERY TEST OF A FULL-SCALE FREE-FLIGHT MODEL OF AN AIR-TO-SURFACE MISSILE WITH RECOVERY INITIATED AT A MACH NUMBER OF 1.43*

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SUMMARY

A five-stage dual-parachute recovery system, designed to recover a prototype air-to-surface guided missile during developmental test firings, has been flight-tested on a ground-launched, rocket-boosted, full-scale model weighing 1,368 pounds.

A trajectory was selected for the model to approximate closely the flight operating conditions for the two recovery parachutes. Recovery of the model was initiated at a Mach number of 1.43 and a dynamic pressure of 1,753 lb/sq ft.

The maximum loads experienced by the FIST ribbon-type drogue parachute were approximately 8,000 pounds when opened to the reefed stage and about 9,850 pounds when opened to the fully blossomed condition. The maximum loads experienced by the extended-skirt main parachute were less than the design loads.

Parachute drag data have been presented for Mach numbers from 0 to 1.43, and the flight program is discussed.

INTRODUCTION

The recovery of large prototype missiles during developmental test firings is attractive for several reasons. Since missiles with complex guidance and propulsion systems are expensive, it is obviously an economic advantage to recover the test vehicle for repeated use. This advantage is especially real where a specific configuration must undergo a lengthy series of flight tests. Recovery of the test vehicle also

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provides an opportunity to determine the cause of any system malfunction which may occur during the flight. For these reasons, there is much interest at this time in the parachute as a recovery device.

An air-to-surface, rocket-powered missile under development for the Navy will employ a five-stage dual-parachute system for recovery of the missile from supersonic speeds during developmental test firings. The Applied Materials and Physics Division of the National Aeronautics and Space Administration assisted in the evaluation of the proposed parachute recovery system by proof-testing this system on ground-launched, rocket-boosted, full-scale dummy models of the missile.

A booster system was selected and trajectories were planned with which the desired flight operating conditions of the parachutes could be approximated with a model in free flight.

Although the test discussed herein was conducted by the missile contractor in cooperation with personnel of the White Sands Missile Range, previous tests (unpublished) conducted at the NASA Wallops Station with the same test vehicle contributed to the development of the recovery system used in this test. Such modifications as an increase in the allowable load limit of the drogue-parachute attachment points, a change in the drogue-parachute suspension-line arrangement, changes in parachute packaging, and deployment scheduling were made on the basis of results of the previous tests conducted at the NASA Wallops Station. Selection of the White Sands Missile Range overland site for the test discussed herein was made in order to facilitate recovery and examination of parts or components which might fail to operate properly during the test.

The purpose of this paper is to present the parachute drag data obtained for Mach numbers from 0 to 1.43 and to discuss the flight-test technique used in this program.

MODEL, PARACHUTES, INSTRUMENTATION, AND BOOSTER VEHICLE

Model

A photograph and the dimensions of the model are shown in figure 1 and figure 2, respectively. The model had a fineness ratio of 9.3 and consisted of a truncated-cone forebody with an ogive nose, a cylindrical centerbody, and a conical afterbody. The model was 14.7 feet long and had a maximum diameter of 19.0 inches in the centerbody. A 4.0-percent-thick clipped delta wing having a leading-edge sweepback angle of 62.1° and an aspect ratio of 1.74 was [redacted] the bottom of the fuselage. Four stabilizing fins (also having clipped delta planforms) were interdigitated with respect to the wing. Since this model had no guidance or control, a single, larger, vertical fin was mounted on top of the fuselage to increase directional stability at the higher Mach numbers.

The entire model was fabricated from steel and had a total weight of 1,368 pounds. The center of gravity was 100 inches behind the nose. These conditions were selected to duplicate those of the prototype missile at initiation of recovery.

Parachutes

The recovery parachutes (drogue and main) were stored in separate canisters in a compartment on the left side of the fuselage as shown in figure 2. A jettisonable hatch cover for this compartment was secured to the fuselage with explosive bolts that released the cover when drogue-parachute deployment was initiated. The parachutes were propelled into the airstream by explosive charges placed beneath their respective canisters.

The drogue parachute was a 22-percent-porosity, FIST ribbon-type, nylon parachute having a flat diameter (cloth diameter when spread out on a flat surface) of 5.4 feet. A reefed stage, having a diameter of 1.5 feet at the reefing cord, was employed to reduce the initial load experienced by the drogue parachute. The drogue parachute was suspended from the model by twin nylon risers that attached to mounting lugs on the top and the bottom of the fuselage 176.5 inches behind the nose.

The main recovery parachute was made of nylon cloth and had a flat diameter of 37.1 feet. A photograph of the unreefed main parachute (taken during a preflight check) is shown in figure 3. Two reefed stages, having diameters of 2.6 feet and 3.8 feet at the reefing cords, were used to reduce the loads experienced by the main parachute. Reefing cords on both parachutes were severed with reefing cutters. The main parachute was suspended from the model by a single nylon riser line that was attached to a swiveled fitting inside the parachute storage compartment at a station 143.8 inches behind the nose. Figure 4 is a sketch showing both of the inflated parachutes and their suspension arrangements. Dimensional data are also shown in this figure. Design allowable limit load, as stated by the contractor, is 12,000 pounds for both drogue parachute and main parachute.

Instrumentation

Drogue-parachute load data were measured with load cells installed on the model at the drogue-parachute attachment points and were telemetered in flight to a ground receiving station. There was no load-cell instrumentation on the main parachute. Accelerations along the longitudinal and normal body axes were measured near the center of gravity of the model. Total pressures were also measured in flight. The contractor installed all model instrumentation and supplied and operated the ground receiving station.

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Velocity and trajectory data were obtained with the White Sands Missile Range theodolite system. Mach number and dynamic pressure were reduced from measured values of velocity and atmospheric data obtained with an atmospheric sounding balloon.

Booster Vehicle

An Honest John rocket motor was used to boost the model to supersonic speeds. This rocket motor produced a burnout velocity greater than the desired recovery-initiation velocity and allowed for a free-flight model coast period after model-booster separation prior to parachute ejection. The standard military Honest John fins were replaced by fins (designed by NASA) which had an exposed area of 12 sq ft per panel. These fins provided adequate stability for the model-booster combination during powered flight and no other stabilization was required. The fins were mounted at an angle of incidence of 0° with respect to the booster thrust line and were interdigitated 45° with respect to the model wing plane. The vertical center of gravity of the model was alined with the booster thrust line in order to eliminate thrust misalinement and reduce aerodynamic trim. A drawing of the model-booster combination is shown in figure 5. The following table presents the weights of the various components in the model-booster combination:

Weight of Honest John rocket motor, lb:	
Loaded	3,880
Burned out	1,830
Weight of booster fins, lb	414
Weight of adapter (booster to model), lb	431
Model weight, lb	1,368
Total weight of model-booster combination, lb:	
Loaded	6,093
Burned out	4,043

FLIGHT TEST

The model-booster combination was launched at an elevation angle of 50°. A photograph of the model and booster on the launcher is presented as figure 6. The recovery parachutes were deployed at preselected times after launch by means of an automatic timer. The following table is a schedule of events of the recovery test (as determined by telemetry data) and also presents corresponding values of altitude, velocity, dynamic pressure, and Mach number:

Event	Time from launch, sec	Altitude above sea level, ft	Velocity, ft/sec	Dynamic pressure, lb/sq ft	Mach number
Launch	0	4,000	0	0	0
Model-booster separation	7.24	10,700	1,910	3,010	1.73
Stage 1: drogue parachute deployed, reefed	11.43	15,100	1,580	1,753	1.43
Stage 2: drogue parachute unreefed	15.65	17,600	920	563	.85
Stage 3: main parachute deployed, reefed	61.10	8,600	320	84	.28
Stage 4: main parachute, second reefed stage	64.40	7,600	245	52	.22
Stage 5: main parachute unreefed	67.50	7,000	120	11	.10
Model impact	141	4,000	40	2	.04

Figures 7 and 8 are photographs taken during the recovery test and show, respectively, the drogue parachute deployed and the main parachute deployed. The drogue parachute is normally jettisoned before main parachute deployment, but for this test it was purposely held attached to the model (see fig. 8) so that it could be recovered and examined for possible damage.

ACCURACY

Maximum errors of the accelerations and the combined load-cell data as supplied by the contractor and the theodolite as given by the

White Sands Missile Range are tabulated as follows:

Longitudinal accelerations (for a ±10.0g range), g units	±1.0
Normal accelerations (for a ±10.0g range), g units	±1.0
Combined load-cell values, lb	±400
Velocity, ft/sec	±25

The frequency response of the accelerometers was about 40 cycles per second.

RESULTS AND DISCUSSION

All the data presented herein were made available to the NASA by the contracter.

Figure 9 shows the model altitude as a function of horizontal range, as determined with the White Sands Missile Range theodolite system. Mach number, velocity, and dynamic pressure are shown as functions of time in figure 10. The increase in velocity and Mach number beginning at about 30 seconds after launch occurred after the model passed the apogee of its trajectory and started on a descending flight path. Velocity values in figure 10(b) show an average descent rate of 40 ft/sec with the main parachute fully open (stage 5).

Figure 11(a) shows a portion of the time history of the indicated longitudinal and normal accelerations for the model alone (just prior to parachute deployment) and for the model—drogue-parachute combination as obtained from the accelerometers. Since the accelerometers were mounted slightly off the center of gravity of the model, they indicate not only the translatory accelerations but also the accelerations due to angular velocities and angular accelerations. The angular motions were not measured and therefore the parachute loads reduced from the indicated longitudinal accelerations are only an approximation of the true parachute loads.

Figure 11(b) presents a comparison of drogue-parachute loads obtained from the load cells and drogue-parachute loads reduced from the longitudinal accelerations of figure 11(a). The load cells measure drogue-parachute loads only, whereas the accelerometer indicates the loads of the model-parachute combination. In order to compare these two sources of data, it was necessary to subtract the drag of the model alone (drag indicated by the longitudinal accelerometer just prior to drogue-parachute deployment) from the drag of the model-parachute combination.

Since recorded data indicated that one of the load cells failed to function correctly during the test, the curve for the load-cell data in figure 11(b) was determined by doubling the values obtained with the cell that appeared to function properly. It is believed that this procedure would not introduce any great error in the load-cell data because the drogue-parachute suspension system allowed approximately an equal distribution of loads between the two load cells at the attachment points. (See fig. 4(a).) The poor agreement between load-cell data and accelerometer data near 16.0 seconds (stage 2) in figure 11(b) is believed to be largely due to an angular rotation of the model which caused low indicated values of longitudinal acceleration. The relatively large increase in normal acceleration near 16.0 seconds (fig. 11(a)) indicates that the model was pitching at this time.

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The load-cell data of figure 11(b) indicate maximum load values of 8,000 pounds for the reefed drogue parachute and 9,850 pounds for the unreefed drogue parachute.

As stated earlier the drogue parachute was held attached throughout the model flight, but the load cells indicated that the drogue-parachute drag was essentially zero after main-parachute deployment.

Measured values of longitudinal and normal accelerations of the model—main-parachute system are shown as a function of time in figure 12(a), and the incremental loads due to main-parachute deployment are shown in figure 12(b). The incremental loads were obtained by subtracting the drag of the model—drogue-parachute combination (drag indicated by the longitudinal accelerations at 61.0 seconds, just prior to main-parachute deployment) from the total drag indicated after main-parachute deployment. These incremental loads (fig. 12(b)) indicate that the maximum loads experienced by the main parachute were well within the 12,000-pound design load condition.

Total drag of the model and parachutes in terms of the parameter $\frac{\text{Drag}}{\text{Dynamic pressure}}$ is presented as a function of Mach number in figure 13. Values of total drag used in determining this parameter were reduced directly from measured values of longitudinal accelerations.

CONCLUDING REMARKS

A five-stage dual-parachute system has been used successfully to recover a 1,368-pound model of an air-to-surface missile with recovery initiated at a Mach number of 1.43 and a dynamic pressure of 1,753 lb/sq ft. The loads experienced by the parachutes during this recovery test did not exceed the design conditions (12,000 pounds allowable limit load) of the parachutes. The descent speed of the model with main parachute unreefed was approximately 40 ft/sec at an altitude of 4,000 feet above sea level.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 3, 1960.

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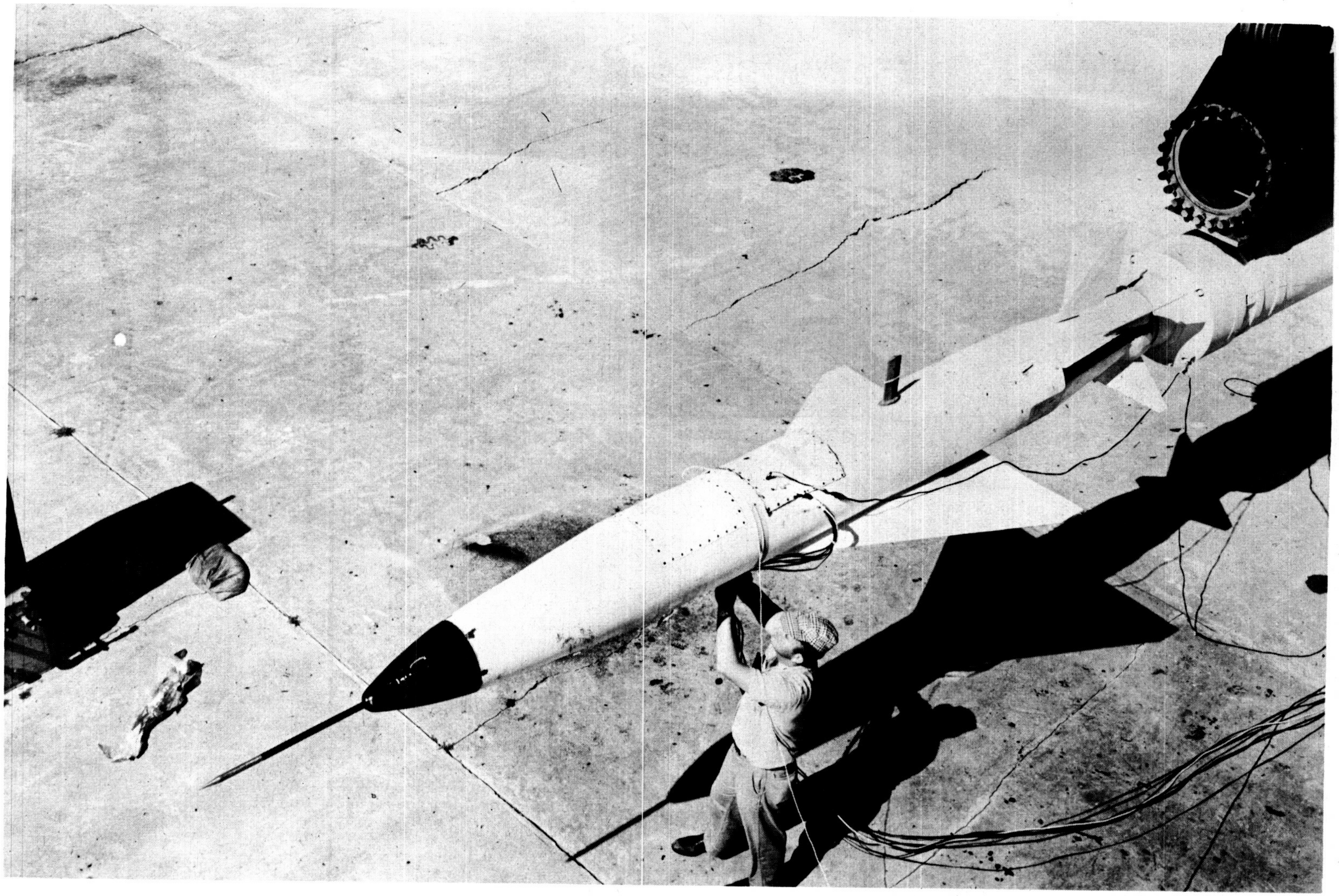

Figure 1.- Model readied for launching. L-59-6322

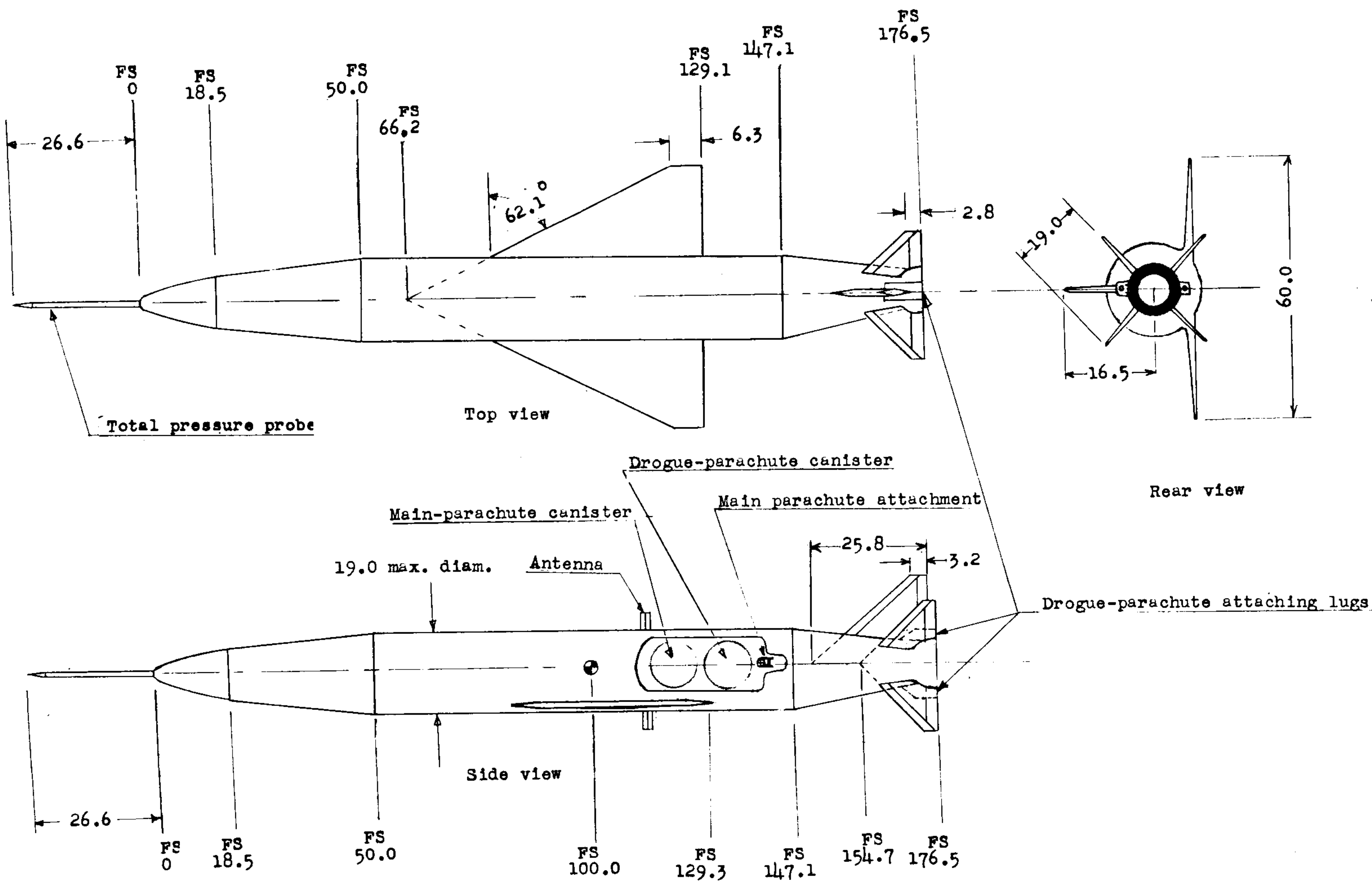

Figure 2.- Three-view sketch of the model. All dimensions and fuselage stations (FS) are given in inches.

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Figure 3.- Main recovery parachute in the unreefed condition. L-60-6930

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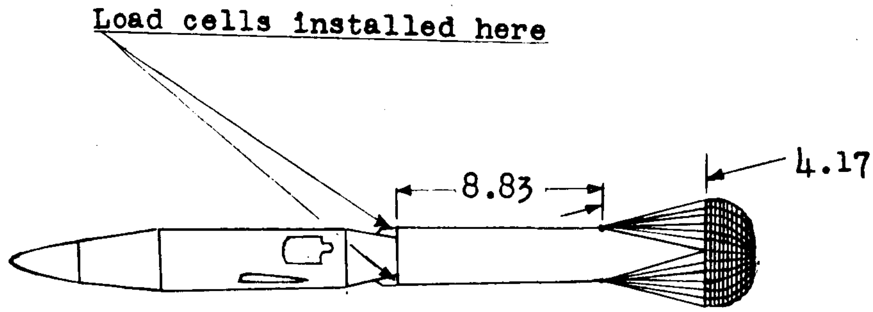
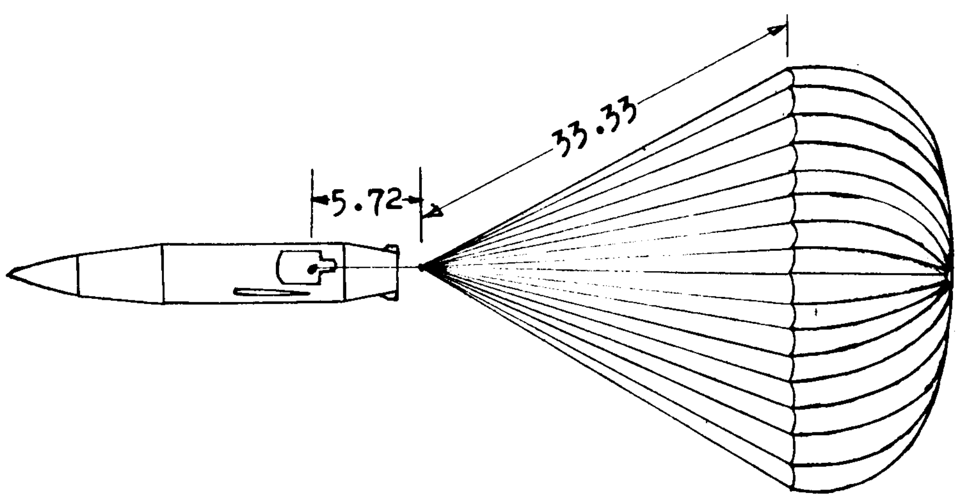


(a) Drogue parachute.

Stage	Flat diam., ft	Reefing line diam., ft
1	-	1.5
2	5.4	-
3	-	2.6
4	-	3.8
5	37.1	-



(b) Main parachute.

Figure 4.- The recovery parachutes in the fully blossomed condition. (Not drawn to scale.) All dimensions are in feet.

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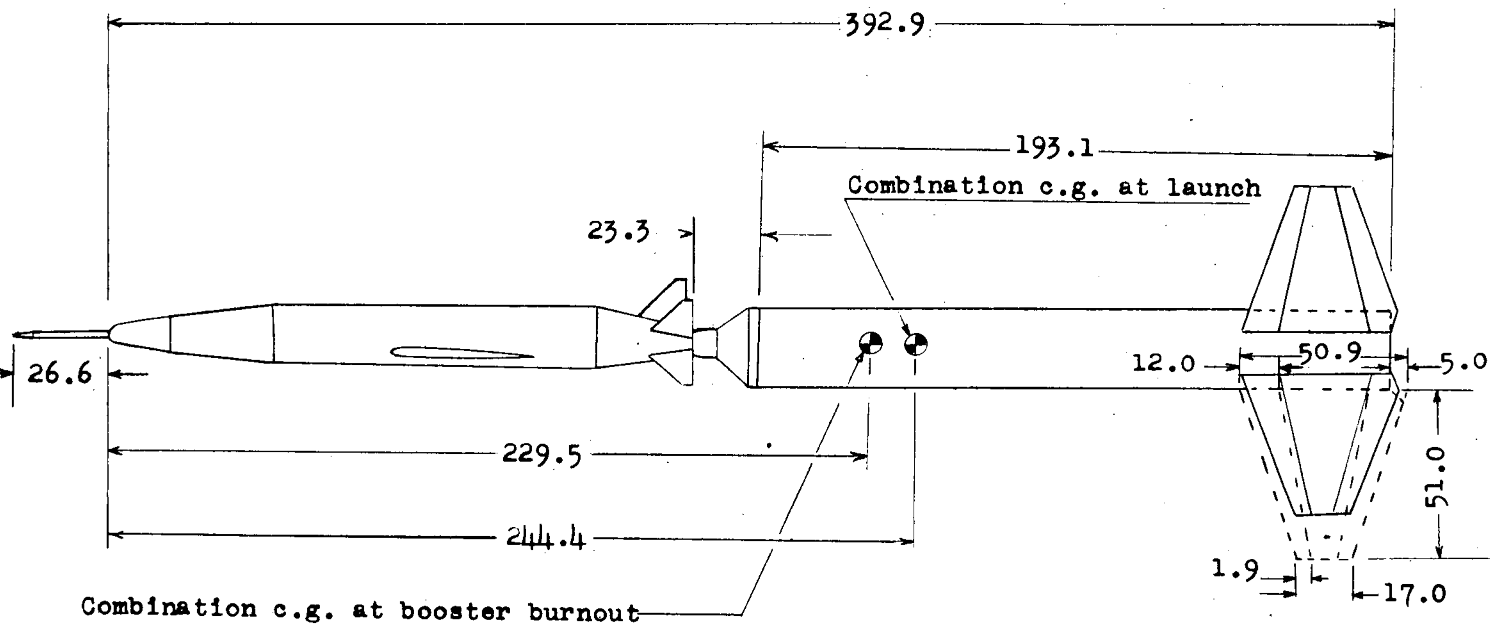
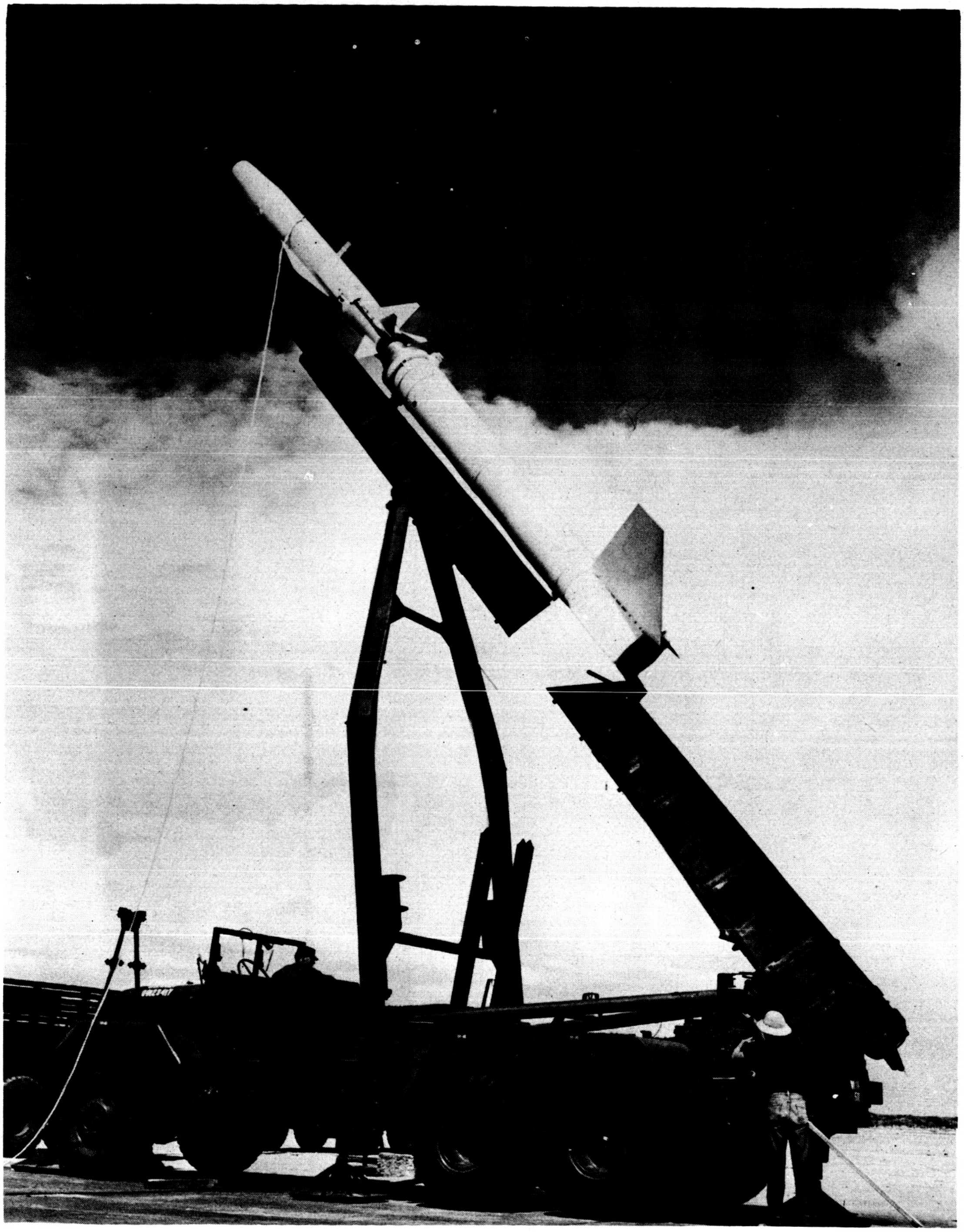


Figure 5.- Model-booster combination. All dimensions are in inches.

[redacted]



L-60-6931

Figure 6.- Model-booster combination on launcher.

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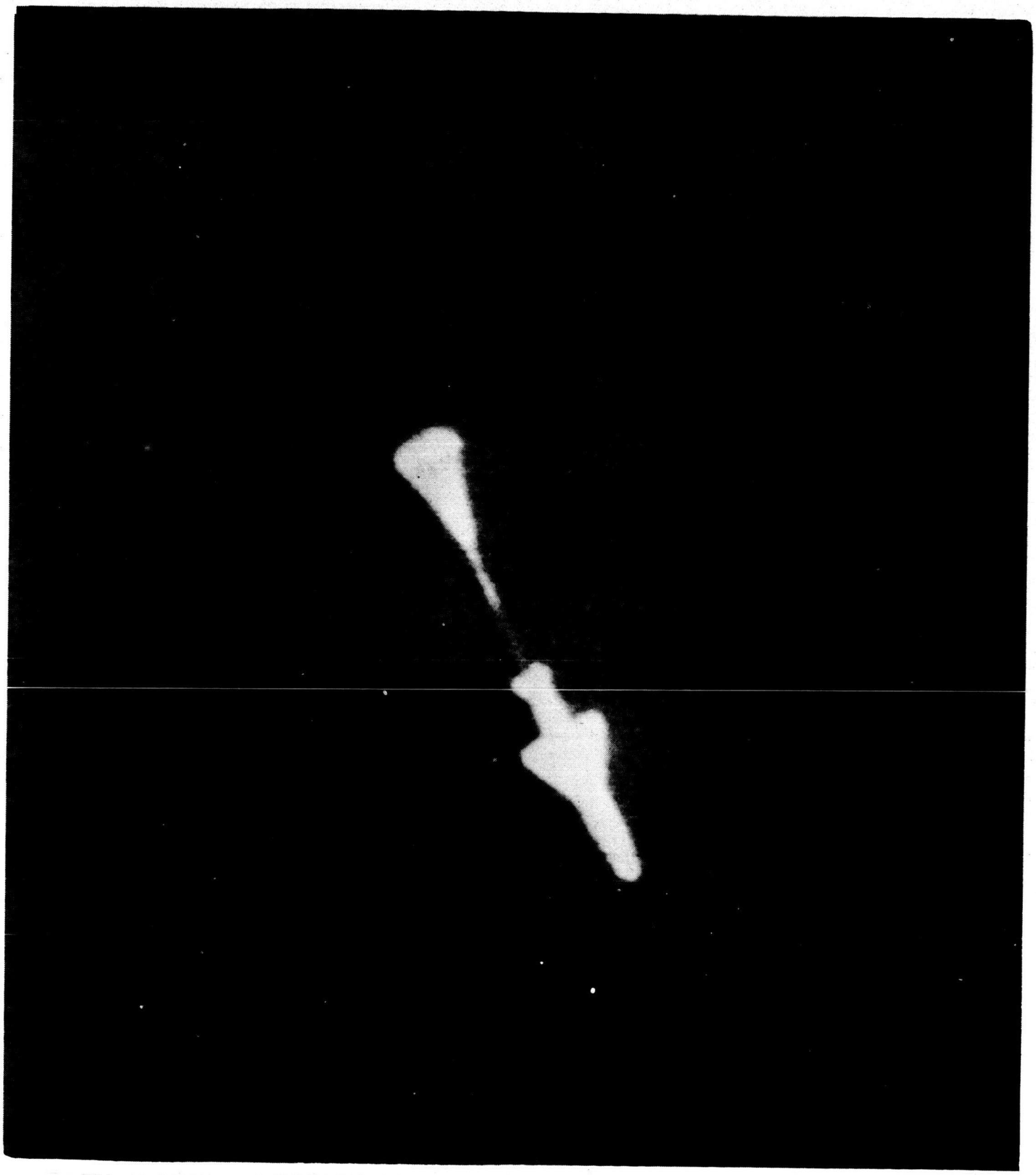

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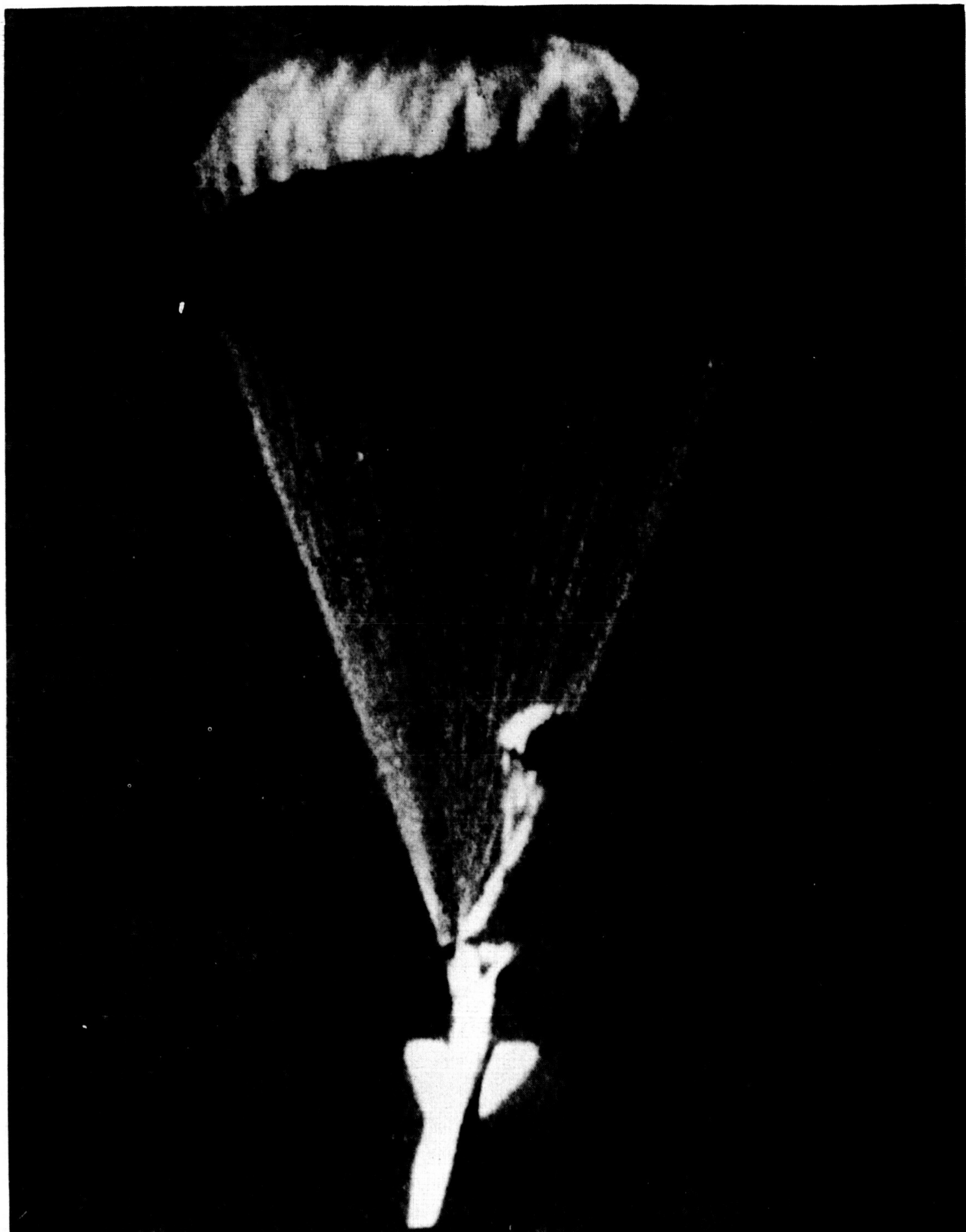
Figure 7.- Drogue parachute in unreefed condition.

[redacted]

[redacted]



L-60-6933

Figure 8.- Main parachute in unreefed condition. (Drogue parachute attached.)

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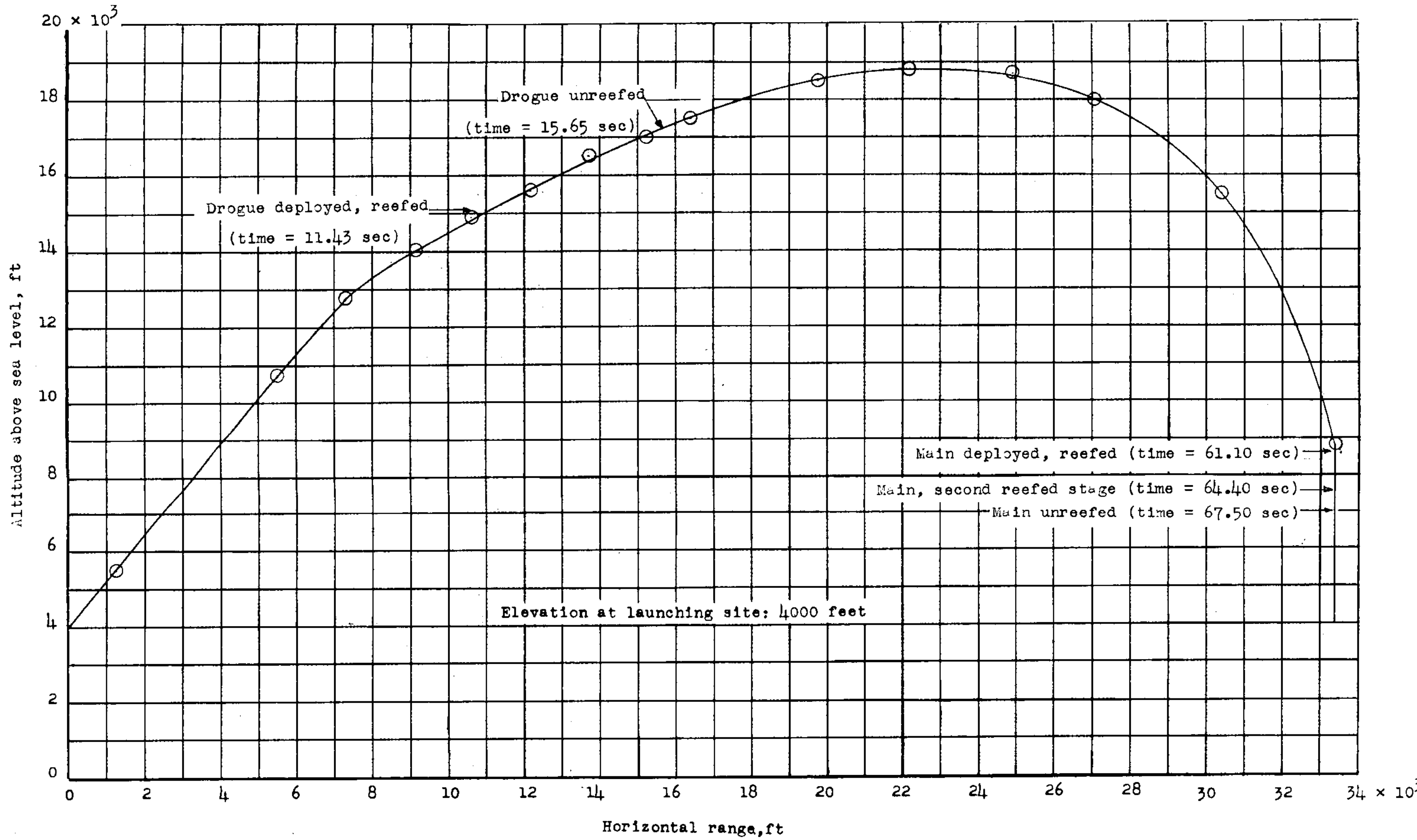

Figure 9.- Trajectory of model.

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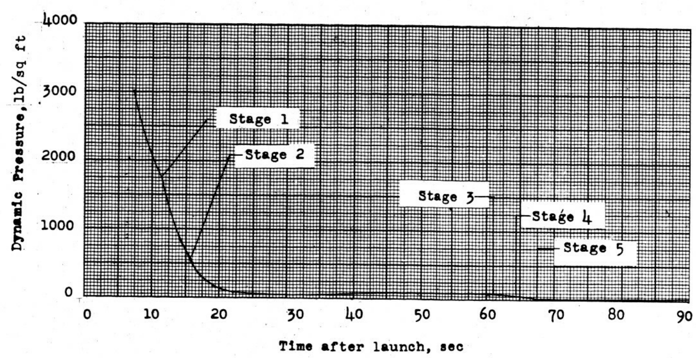
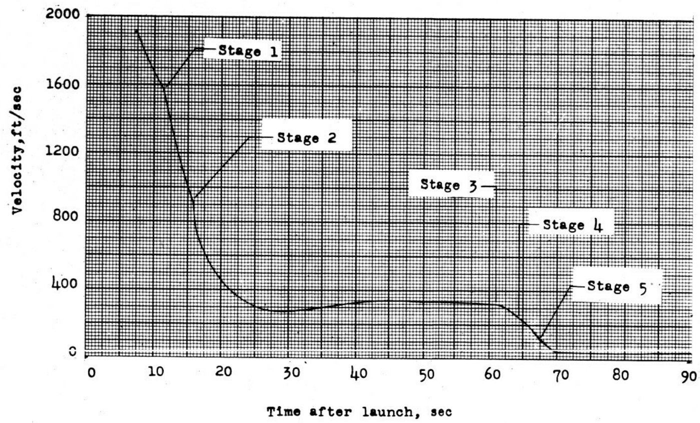
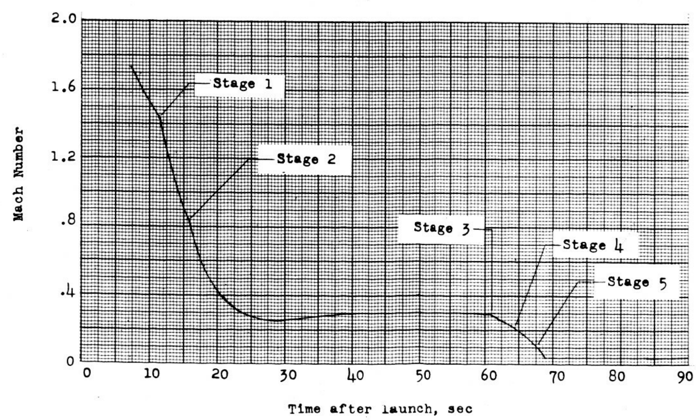


(a) Dynamic pressure.



(b) Velocity.



(c) Mach number.

Figure 10.- Variation of test conditions with time after launch.

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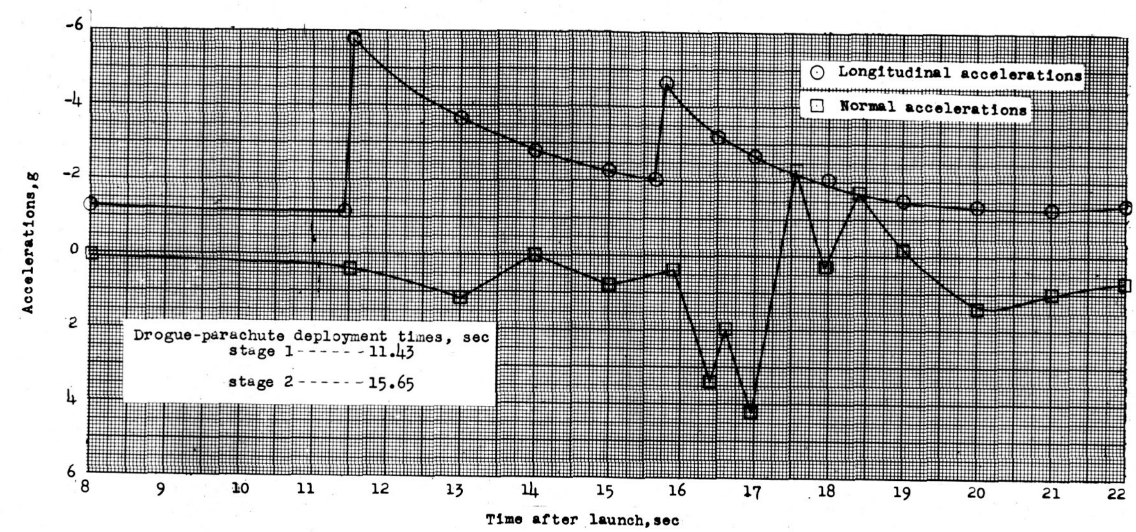
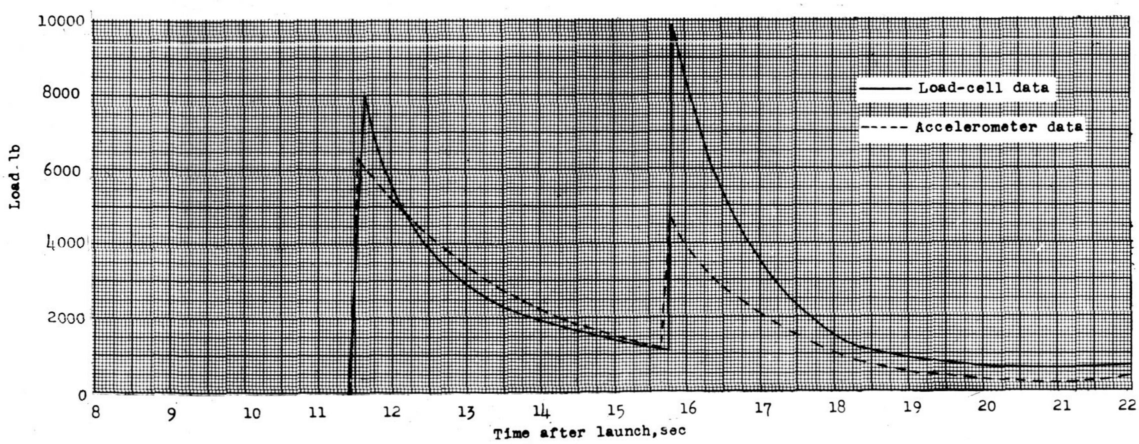


(a) Longitudinal and normal accelerations.



(b) Drogue-parachute loads.

Figure 11.- Measured longitudinal and normal accelerations of the model—drogue-parachute system, and a comparison of drogue-parachute loads, measured with load cells, with drogue loads reduced from the longitudinal accelerations.

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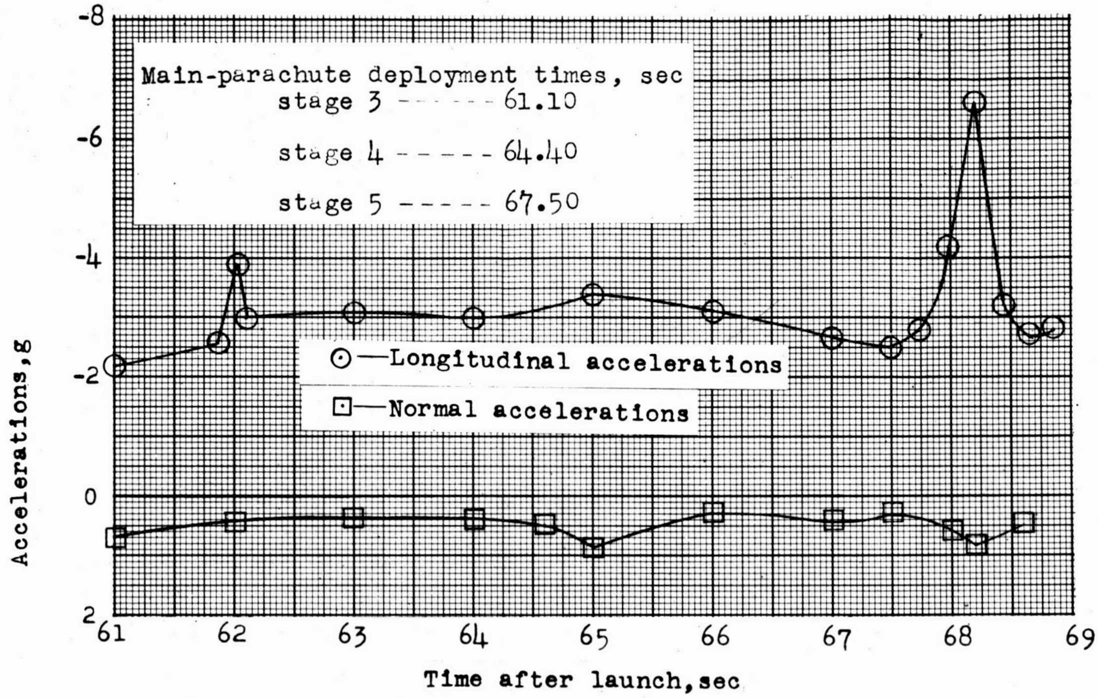
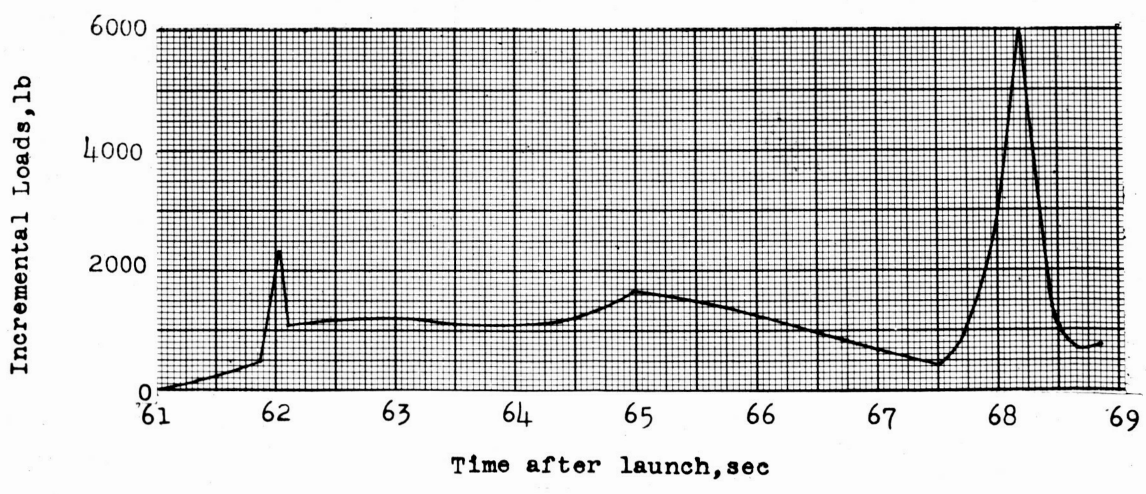


(a) Longitudinal and normal accelerations.



(b) Main-parachute loads.

Figure 12.- Measured longitudinal and normal accelerations of the model—main-parachute system and incremental loads reduced from longitudinal accelerations.

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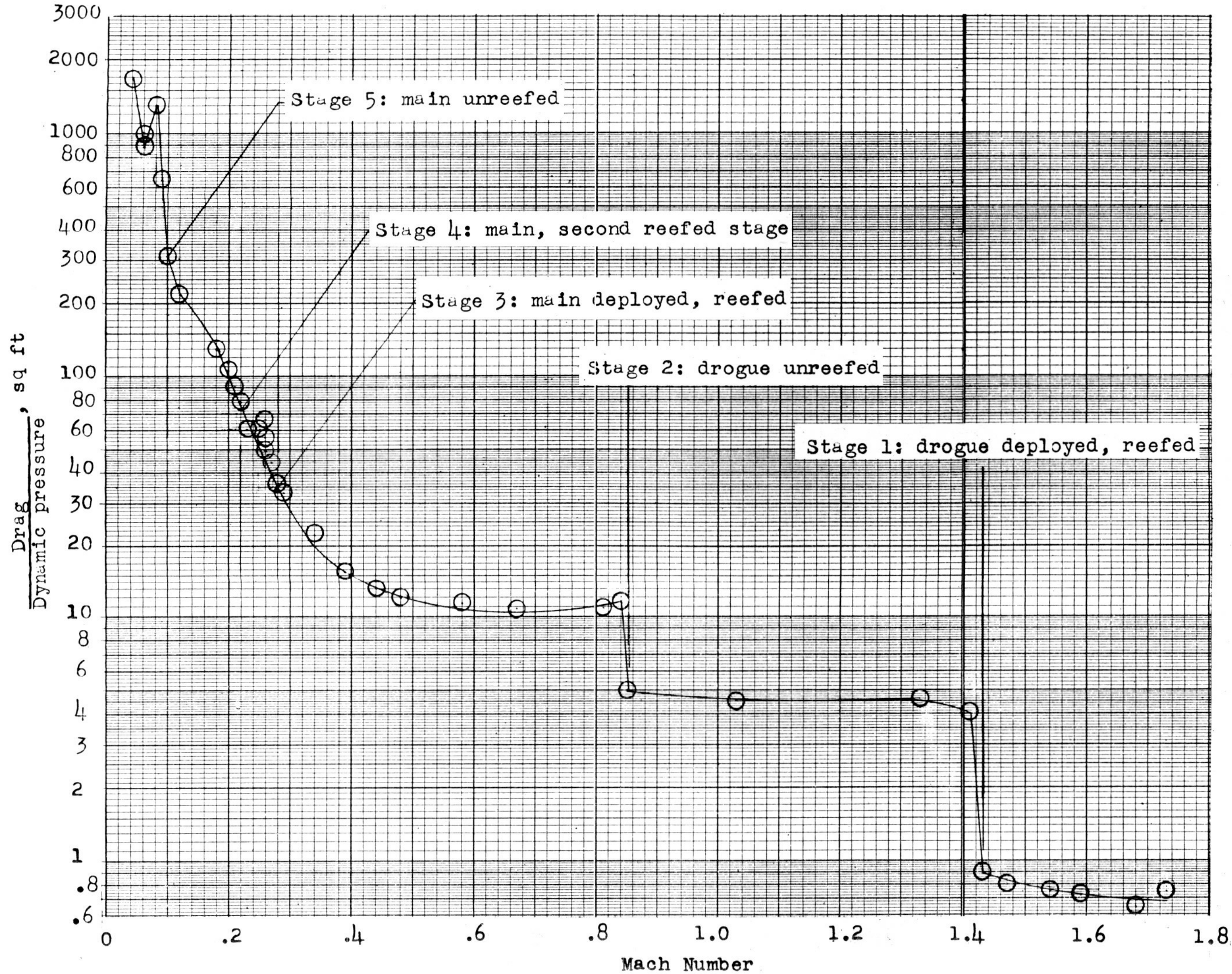

Figure 13.- Total drag of recovery parachutes and model.

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